Forest Conservation and CO2 emissions: A Viable Approach

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Natural Risks, climate change, natural and renewables resources, LEF

Nancy, 7 septembre 2010

Sommaire

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Sustainable Development
A meaning to identify precisely

The concept ≪ **Sustainable Development** ≫ is widely adopted, however finding explicit ≪ **Sustainable** ≫ strategies is difficult.

What means :

- to be sustainable ?
- to satisfy or to reach an objective ?
- to satisfy, to manage, to impose constraints ?
- to preserve resources ?
- to guarantee the welfare of different generations ?
- to preserve equity between successive generations ?

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Sustainable Development
A mathematical vocabulary

Mathematical concepts are needed for analysing complex dynamical systems

- define a **state** : $x \in X = \mathbb{R}^n$,
- define state **constraints** : K ,
- precise **parameters** : p ,
- consider the **dynamics** of the state evolution : $x'(t) \in F(x(t), p)$,
- consider **controls** or **regulons** that formalise possible actions on the evolutionnary system : $F(x,p) = \{f(x,p,u),\ u \in U(x)\}$,
- consider non controlable **perturbations** : $F(x,p) = \{f(x,p,u,v),\ u \in U(x),\ v \in V\}$.

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A fundamental ethic concept

Sustainability and Equity

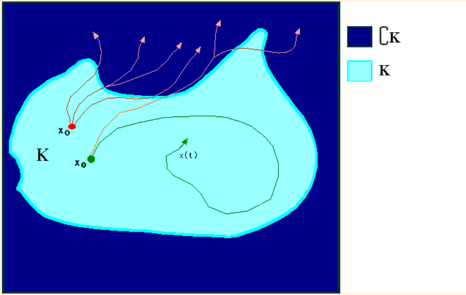
La **Sustainability** is a notion which refers to different “qualitative criteria ” such as :

- the non decrease of ...
- the maintenance of ...
- the return back to ...
- the compatibility between ...

Mathematical translation of ethic concepts
Sustainability / Equity / Viability

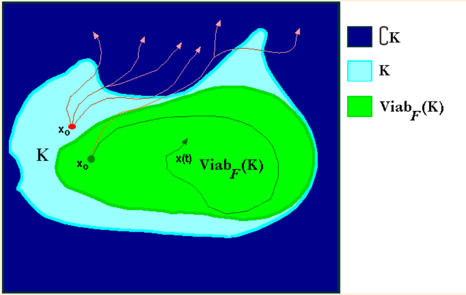
- Viability Theory was developed in order to answer to these challenges.
- It addresses Sustainability in term of respecting constraints at any time and Equity in term of respecting thresholds on some state variable variation at any time and finding decisions on time.
- Depending on context one can construct “Viability Tools” which answer to Sustainability problems as soon as they are well identified.
- Aiming at measuring impact or at optimizing a criteria, it is possible, in return for higher algorithmic complexity, to give answer for problematics where sustainability and optimality interfere.

A fundamental mathematical concept : Dynamics and Constrains



An environment is described by a set of constraints ***K*** . The evolution is governed by a law ***f*** dependent of a parameter variable ***u***.

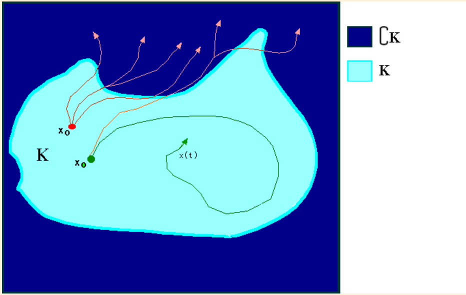
A fundamental mathematical concept :
The Viability Kernel



It is the set of the states in the environment K from which starts *at least* an evolution that remains always in K . All viable evolution remains necessarily always in $Viab_F(K)$.

A fundamental mathematical concept :

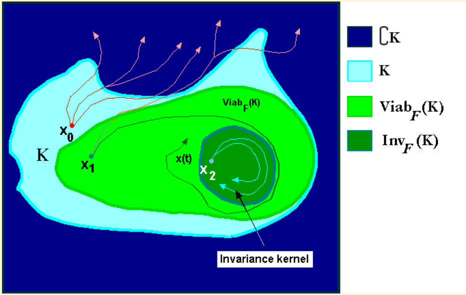
Dynamics and Constrains



Now the evolution is submitted to unpredictible uncertainty described by a law ***f*** depending on a parameter variable ***v***.

A fundamental mathematical concept :

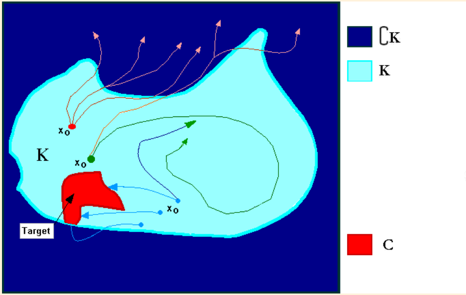
The Invariance Kernel



It is the set of the states in the environment ***K*** from which *all* evolution starts that remains always in ***K*** .

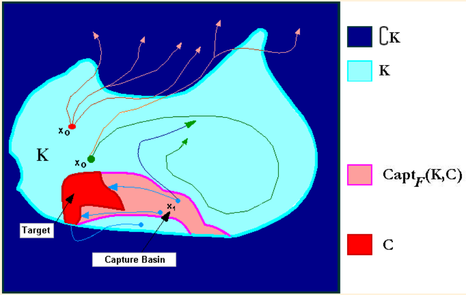
A fundamental mathematical concept :

... And To Reach a Target in Finite Time



Evolutions must remain in ***K*** until they reach a target at some fixed time or in finite time.

A fundamental mathematical concept :
The Capture Basin



The capture basin of the target, viable in an environment, is the subset (possibly empty) of the states of the environment ***K*** from which *at least* one evolution remains *viable* in the environment until it reaches the target *in finite time*..

Constraint Management and Objective Realization

Viability Theory is devoted to fulfilling various objectives while keeping physical or normative constraints
but new set of problems emerge, for instance :

- What normative constraints adjustments are necessary to fulfill sustainability and equity of at least one evolution starting from the actual situation ?
- What decision or policy must be taken so as to ensure "Sustainability" and "Equity" ? What cost ?
- In more general case, what can be done if "Sustainability" and "Equity" seems not to be achievable in the actual context ?

Sommaire

Questions Read Through Applications
Some Environmental Modeling

- Tropical Forest : (with Sophie Martin (LISC, Clermont-Ferrand) and Claire Bernard)
  - A problem of biodiversity conservation
  - A local and global model
  - Coupling economy, society and environment
- World Forest :(with Pablo Domenech and Georges Zaccour (GERAD, HEC Montreal))
  - A environmental problem
  - A global model
  - Coupling economy and environment

(DEDUCTION - ANR Project)

Preservation of Biodiversity in Fianarantsoa Corridor

- **The Sustainability Problem** :
  An increasing and lacking in revenue population look for lands for cultivating in a context where soil property rights do exist only for cleared lands.
  - ➢ there is not necessarily incompatibility between biodiversity protection and subsistence agriculture maintenance.
  - ➢ consider the poverty problem face to numerous legal, cultural, environmental , agronomic, biologic, economic or social questions at stake.
- **The Model to be consider** :
  - ➢ is a coexistence model between population activity and environment preservation

The Humid Tropical Forest :
A Coexistence Population/Environnement Model

This coexistence model aims at

- determining conditions for preserving a certain amount of forest surface in the Fianarantsoa corridor,
- characterizing appropriate regulations of population,
- evaluating necessary monetary transfers,
- suggesting economical development and employment strategies,

which allows biodiversity preservation of the forest and autochthon population welfare.

The Humid Tropical Forest :

A Coexistence Population/Environnement Model

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Forest Conservation and CO2 emissions: A Viable Approach

The Humid Tropical Forest :

The model

- ***S*** the surface dedicated to agriculture (ha) ;
- ***N*** the population level ;
- ***K*** the capital).

$$
\begin{aligned}
S'(t) &= d(t) \\
N'(t) &= r(t)N(t) - v(t)N(t) \\
K'(t) &= -\underline{c}N(t) - \beta_S(t)d(t) + \\
&\quad \mu \min(S(t), \gamma(1 - v(t))N(t)) + \\
&\quad \omega v(t)N(t) + \tau(t)
\end{aligned}
$$

The Humid Tropical Forest : Coexistence

Parameters

- The different parameters in the model :

  F_0 : **forest surface in 1900** (ha)

  $\underline{c}$: **minimal level of consumption** (US$)

  d_{max} : **maximal surface can be converted into culture** (ha per capita)

  γ : **maximal cultivable surface** (ha per capita)

  ω : **individual wages** (US$ per capita)

  $\beta_S(t)$: **land use planning cost** (US$ per ha)

  μ : **net revenue per ha** (US$)

  F_{min} : **minimal surface of primary forest** one want to preserve (ha)

- The population growth rate is let "free" : $r(t) \in [r_{min}; r_{max}]$ playing the role of a regulon ; Viability analysis will reveal population regulations that are compatibles with **Sustainability**.

The Humid Tropical Forest : Coexistence

Economical Mechanisms

- Four controls or “regulons” :

$d(t)$: **land use planning effort** (ha per year) : additional surface to be converted (clearing, irrigation network,...) :

$$0 \leq d(t) \leq N(t) d_{max}$$

where d_{max} is the maximal convertible surface per capita and year ;

$v(t)$: **Proportion of wage-earners** who may work somewhere else or apply for another activities for a while :

$$0 \leq v(t) \leq 1$$

$r(t)$: **Population growth rate**.

$$r_{min} \leq r(t) \leq r_{max}$$

$\tau(t)$: **Monetary transfer** (US$ per year) : support that the international community is ready to pay to local institutions on biodiversity conservation account.

$$0 \leq \tau \leq \tau_{max}$$

Maintain biodiversity of primary forests and ensure an acceptable living standard to local populations, that is :

- an ecological constraint : preserve a minimal surface of primary forest : $0 \leq S \leq F_0 - F_{min}$
- economical constraints,
  - secure a global and individual capitals :

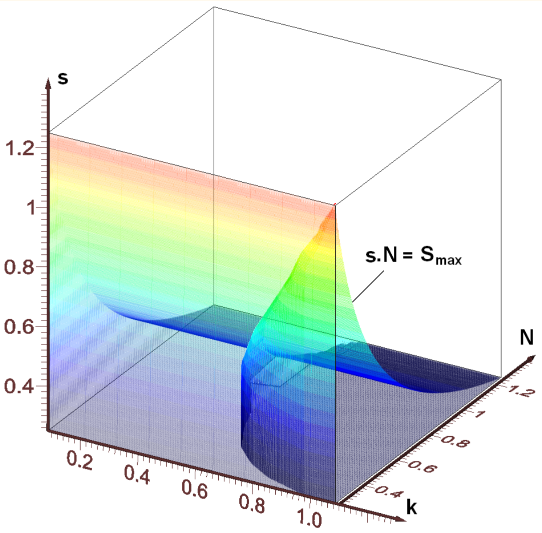
$$K_{current} \leq K \text{ and } \frac{K_{current}}{N_{current}} \leq \frac{K}{N}$$

  - ensure a non decreasing revenue per capita :

$$\left(\frac{K}{N}\right)' \geq 0$$

The Humid Tropical Forest : Coexistence

What Sustainability ?



The Humid Tropical Forest : Coexistence

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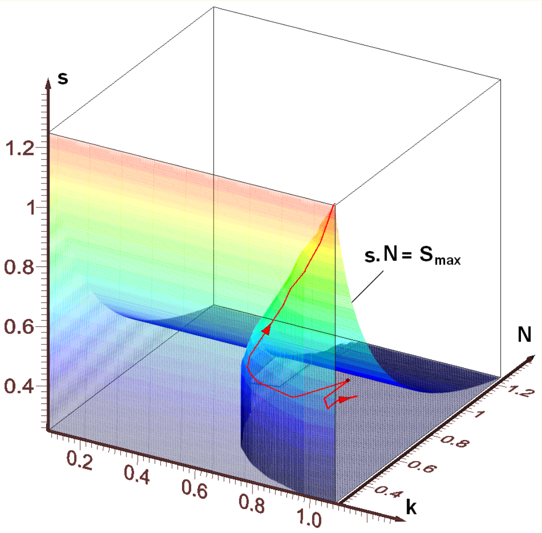

Global Forest :
Managing Forest as Sink of Carbon

- **The Challenge** : Manage world forest as a world public good so as to
  - keep minimal surface necessary to maintain its role of sink of carbon,
  - contain the cumulated CO_2 up to reasonable level,
  - maintain the standard of living of populations who get revenues from forest exploitation,
  - supply the industrial and firewood world demand.
  - determine monetary transfers.

Global Forest :

Managing Forest as Sink of Carbon

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Sustainable Development

Applications

- Biodiversity
- Global Forest

Recovering Sustainability

- Viability Multipliers
- Change Normative Constraints

Global Forest :
The Van Soest and Lensink Model (2000)

Variables :

- ***F*** The **World Forest Stock**, ρ_t and D_t the reforestation and deforestation efforts.
- ***E*** The **Global CO_2 Emissions**.
- ***S*** The **cumulated stock of CO_2** which increases with emissions and decrease with CO_2 forest sequestration.

$$F'(t) = \rho_t + \eta\left(1 - \frac{F_t}{F_0}\right) F_t - D_t,$$
$$E'(t) = V_t \cdot E_t,$$
$$S'(t) = E_t - \varphi F_t.$$

where $V_t \in [V_{min}, V_{max}]$ is a decision variable (emissions adjustment).

Economical Mechanisms

- Global wood supply :

$$q(t) = n \cdot D(t) + n\gamma\delta F(t)$$

- Wood market price

$$P(t) = \overline{P} - \theta q(t),$$

- Analysis of revenues drawn from forest, cleared and cultivated lands :

$$R(t) = P(t)q(t) + P_A\left(\overline{Z} + \frac{\psi\overline{Z}D_t}{F_0 - F(t)} + \frac{\beta F(t)}{F_0}\right)[F_0 - F(t)] + T(t)$$

$T(t)$: Possible monetary transfer "North/South", control variable.

Global Forest : Sink of Carbon

Sustainability ?

In this context, **Sustainability** includes both economical et environmental components :

- Ensure a minimal production : $q(t) \geq \underline{q}$
- Maintain minimal revenues : $R(t) \geq \underline{R}$,
- Preserve a world forest surface and contain carbon emissions and stock under "normal", "consensual" limits : $\forall t \geq 0, \ (F(t), E(t), S(t)) \in K$

where

$$K = \{(F, E, S) \in [F_{\min}, F_{\max}] \times [E_{\min}, E_{\max}] \times [S_{\min}, S_{\max}]\}$$

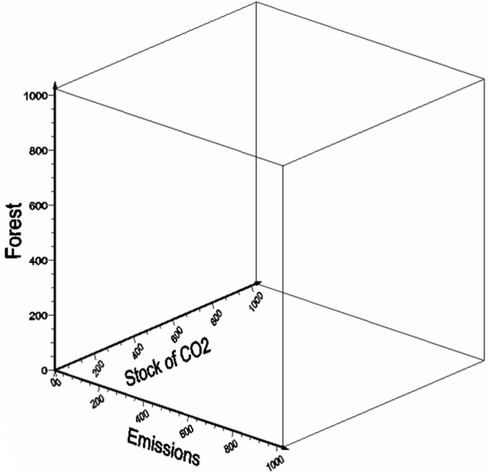
Global Forest : Sink of Carbon

Constraints and Data

$$F_{min} = 0 \text{ million hectares}$$
$$F_{current} = 3925 \text{ million hectares}$$
$$F_{max} = 5500 \text{ million hectares}$$

$$E_{min} = 21.2 \text{ gigatons of } CO_2$$
$$E_{current} = 28 \text{ gigatons of } CO_2$$
$$E_{max} = 42.4 \text{ gigatons of } CO_2$$

$$S_{min} = 0 \text{ gigatons of } CO_2$$
$$S_{current} = 800 \text{ gigatons of } CO_2$$
$$S_{max} = 1653 \text{ gigatons of } CO_2$$



Global Forest : Sink of Carbon

State and Control Variables

- F : **Global Stock of Forest**
- E : **World annual CO_2 emissions**
- S : **Accumulated CO_2 in the atmosphere**
- ρ : **Annual reforestation**
- D : **annual deforestation**

Global Forest : Sink of Carbon

Other Parameters

V : **Possible adjustment velocities of CO_2 emissions**

T : **Monetary Transfers** in US$.

η : **Natural forest growth**

φ : **Absorption rate of CO_2**

$\underline{R}$: **Actual minimal revenue of landholders**

$\underline{q}$: **Minimal wood supply**

n : **Forest exploitation**

Other Parameters

- β : **Floor productivity of the forest**
- γ : **Selective forest exploitation**
- δ : **Fraction of reforested forest**
- θ : **Derivative of the demand function**
- $\overline{P}$: **Floor price for wood**
- ψ : **Extra productivity of deforested land**
- P_A : **Mean Price of good production**
- $\overline{Z}$: **Mean land productivity**

Numerical Results and Decision Policy

One can visualize domains where **Sustainability** is effective or not

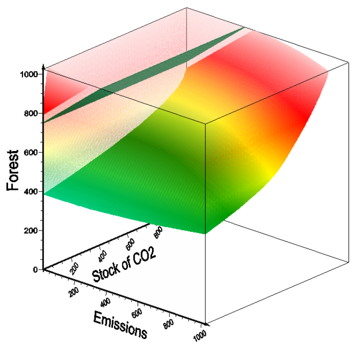


FIGURE: Viability in the lack of economical constraints

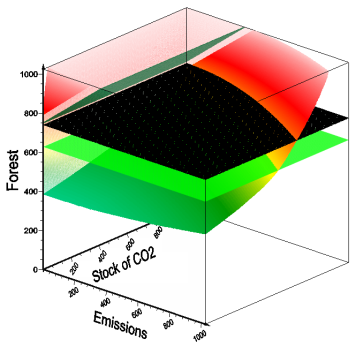


FIGURE: Introduction of economical constraints

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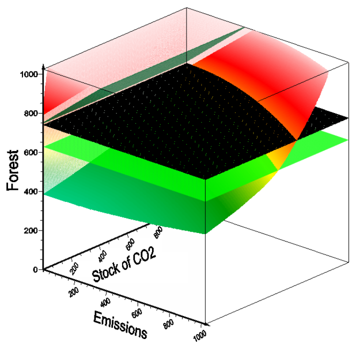

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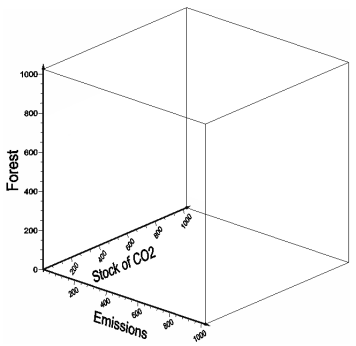

FIGURE: The Viability Kernel is empty : "Sustainability" fails

Sommaire

Viability Tools for recovering Sustainability

Viability Tools for recovering Sustainability :

- Modify the Dynamics : Viability Multipliers.
- Change Normative Constraints,
- Construct Upper Threshold functions,
- Relax Control Set,

Modify the Dynamics : Viability Multipliers

$$X'(t) \in F(X(t), u(t))$$

$$\Downarrow$$

$$X'(t) \in F(X(t), u(t)) + m(t)$$

where $m(t) \in M$.

Problem : Determine M such that

$$Viab_{F,M}(K) \neq \emptyset$$

Exemple : Maintaining Biodiversity through monetary transfers

In the Humid Forest Model :

$$
\begin{aligned}
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N'(t) &= r(t)N(t) - v(t)N(t) \\
K'(t) &= -\underline{c}N(t) - \beta_S(t)d(t) + \\
&\quad \mu min(S(t), \gamma(1 - v(t))N(t)) + \\
&\quad \omega v(t)N(t) + \\
&\quad \tau(t)
\end{aligned}
$$

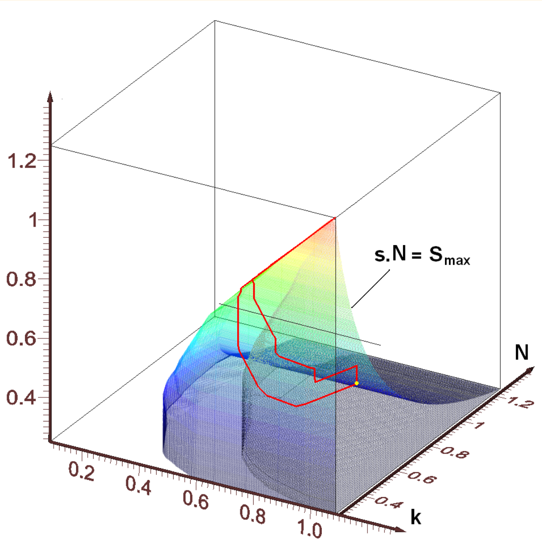
$\tau(t)$ is the monetary flow transfer.

Questions :

- Determine the rule $t \rightarrow \tau(t)$ such that biodiversity can be maintained.
- If one change $\tau(t)$ in $\tau(t) + 1$, What more forest surface it will be possible to preserve.

Exemple : Maintaining Biodiversity

through monetary transfers



Exemple : Maintaining Biomass
through monetary transfers

We modify the revenue constraint by introducing a control variable

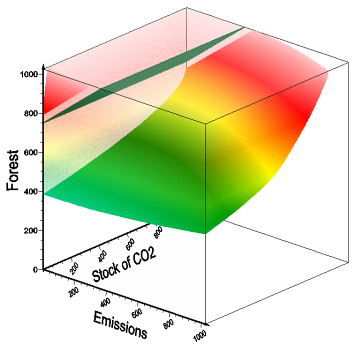
$T(t)$: Possible monetary transfer "North/South"

$$R(t) = P(t)q(t) + P_A\left(\overline{Z} + \frac{\psi\overline{Z}D_t}{F_0 - F(t)} + \frac{\beta F(t)}{F_0}\right)[F_0 - F(t)] + T(t)$$

There exists a time dependent threshold $T^*(t)$ such that $\forall t, \forall T(t) \geq T^*(t)$, both economical and environmental sustainability recover.

Numerical Results and Decision Policy

One can visualize domains where **Sustainability** is effective or not



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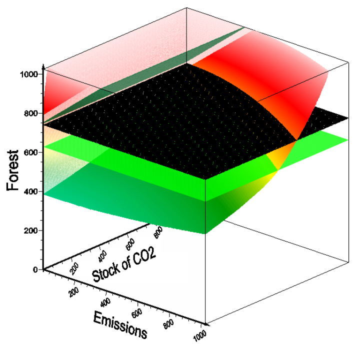

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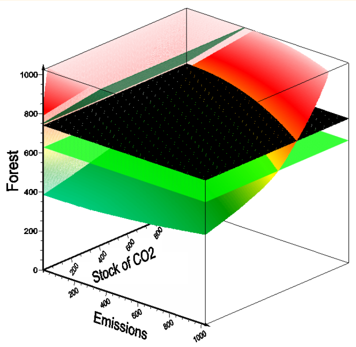

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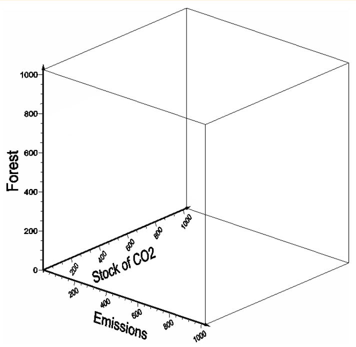

FIGURE: The Viability Kernel is empty : ”Sustainability” fails

Global Forest : Sink of Carbon
Numerical Results and Decision Policy

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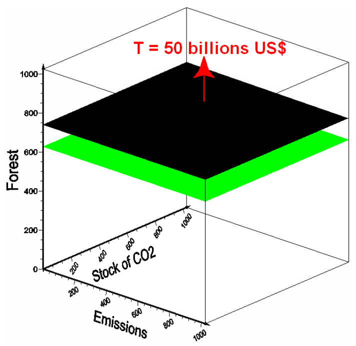
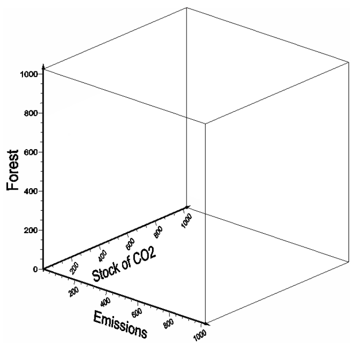


FIGURE: lack of monetary transfer



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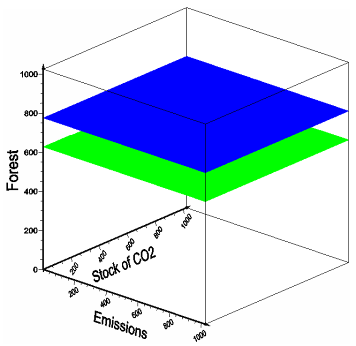

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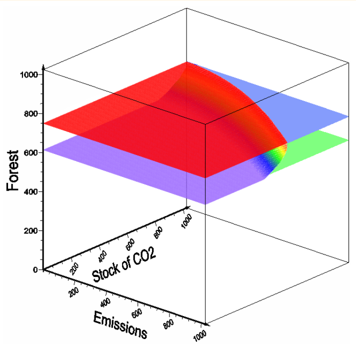
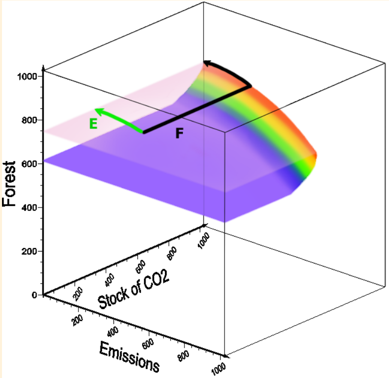


FIGURE: The Viability Kernel is non empty : "Sustainability" become realizable

Numerical Results and Decision Policy

One can visualize decision "Sustainable" rules and select "Sustainable" evolutions.



Conclusion
Applied Viability

- it is a new way to study a dynamical controlled, contrained and tychastic system
- to manage objective
- to measure impact
- in the presence of uncertainty
- but even if the set valued numerical techniques needed to implement viability algorithm require a huge numerical support, the spectrum of potential applications is really very wide

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Forest Conservation and CO2 emissions: A Viable Approach

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Merci

POUR VOTRE ATTENTION